UNCLASSIFIED

AD-A204 187

REPORT DOCUMENTATION PAGE

1b. RESTRICTIVE MARKINGS DTIC FILE COPY	
3. DISTRIBUTION/AVAILABILITY OF REPORT	Approved for public release; distribution is unlimited. (2)
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 88-1311
6a. NAME OF PERFORMING ORGANIZATION: MCR Technology Corporation; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: AFOSR/NP
6c. ADDRESS (City, State, and ZIP Code): P.O. Box 10084, Chicago, IL 60610-0084	7b. ADDRESS (City, State, and ZIP Code): Building 410, Bolling AFB DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: AFOSR; 8b. OFFICE SYMBOL (If applicable): NP	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F49620-87-C-0086
8c. ADDRESS (City, State, and ZIP Code): Building 410, Bolling AFB DC 20332-6448	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61102F	2301	A1	

11. TITLE (Include Security Classification)

(U) DEVELOPMENT OF AN EFFICIENT HIGH BRIGHTNESS TI: A1203 LASER

12. PERSONAL AUTHOR(S)
Drs D. Cullen, W. Haddad, K. Boyer & C.K. Rhodes

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM 15 Aug 87 TO 14 Feb 88	April 1988	13

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
	~~20.06~~		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A 1/4" Ti:Al(2)O(3), rod has been successfully used in the amplification of 200 fs, 745 nm pulses and in the production of 112 ps mode-locked pulses at 790 nm. The results of this testing indicate the lines of further development that should be undertaken in order to design a stable and reliable laser system suitable for short pulse appplications.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: X ☐ UNCLASSIFIED/UNLIMITED X ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: H R Schlossberg	22b. TELEPHONE (Include Area Code): 202()-767-4906 — 22c. OFFICE SYMBOL: NP

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

MCR TECHNOLOGY CORPORATION

P.O. Box 10084
Chicago, IL
60610-0084

(312) 326-5007

11 April 1988

AFOSR-TR- 88-1311

FINAL REPORT

"Development of an Efficient High Brightness Ti:Al_2O_3 Laser Amplifier"

Sponsored by
Defense Advanced Research Projects Agency
DARPA Order No. 4087
Monitored by AFOSR Under Contract No. F49620-87-C-0086

Prepared by: D. Cullen
W. Haddad
K. Boyer
C. K. Rhodes

Prepared for: Dr. Howard R. Schlossberg
AFOSR/NP
Building 410, Room C219
Bolling Air Force Base
Washington, D.C. 20332-6448

CONTENTS

ABSTRACT

Subpicosecond (~ 200 fs) amplification in a flash-lamp excited $Ti:Al_2O_3$ module has been performed. The resulting amplification is sufficient for regenerative operation. Active mode-locking has also been achieved and scaling to a rod diameter of 2" has been examined. These results indicate that $Ti:Al_2O_3$ will be a very good material for short pulse amplification in the near infrared.

I. INTRODUCTION

$Ti:Al_2O_3$ represents an exciting new material with application to many areas including atmospheric research, laser radar, and spectroscopy[1]. It is particularly suitable for short pulse generation, since it has a very large bandwidth.

In the context of short wavelength high brightness sources, MCR Technology Corporation has pursued the development of $Ti:Al_2O_3$ as a system which can be frequency doubled or tripled to produce high energy picosecond and femtosecond duration pulses at short wavelengths[2].

To date we have demonstrated a flashlamp excited device capable of 450 mJ output at 750 nm in a 300 nsec pulse. The overall electrical to optical energy conversion was 0.18%. On the basis of this result, it is projected that overall efficiencies greater than 1 – 2% should be achievable in relatively simple and practical configurations. JES

Amplification of picosecond and femtosecond radiation in $Ti:Al_2O_3$ is an attractive option, since a very broad bandwidth is available with this material. In order to explore this capability, the amplification of ~ 200 fs pulses has been examined.

Direct short pulse generation can also be achieved by a mode-locked $Ti:Al_2O_3$ system. In order to gain an understanding of this process, active mode-locked operation has been studied.

II. RESEARCH FINDINGS

A. Summary of Results

A 1/4" $Ti:Al_2O_3$ rod has been successfully used in the amplification of 200 fs, 745 nm pulses and in the production of 112 ps mode-locked pulses at 790 nm. The results of this testing indicate the lines of further development that should be undertaken in order to design a stable and reliable laser system suitable for

short pulse applications. Below we present the experimental results and the details pertinent to these matters.

B. Laser Design

1. Power Supply Design

The pulsed simmer, spark gap discharge system pictured in Fig. (1) was used throughout these studies. This configuration is similar to designs reported earlier[3,4]. It incorporates a large (in this case pulsed) D.C. current to increase the ionization of the lamp, thus minimizing the impedance, coupled with a spark-gap-triggered capacitive discharge. A continuous simmer current maintains a breakdown in the lamps between shots.

A critical element in this design is the spark gap. If the gap does not ionize fully, then the total energy delivered will vary substantially from shot to shot. The effects of this energy variation were found to be significant. Furthermore, most of the difficulty with the control of the supply resulted from variations in the trigger and the discharge of the gap. This affects the pulse width of the discharge. In these studies, the discharge time was ~ 5 μsec.

Shorter pulse durations could be achieved with a carefully designed Thyratron switching element. With this means, the optical power to the rod could be best optimized.

2. Fluorescence Conversion

The choice of a flashlamp fluorescence converter involves a compromise between efficient conversion and usable lifetime. Several different arrangements have been explored.

Of the various dye combinations, Coumarin 480 in methanol produced the largest output (~ 450 mJ). However, this system suffered from relatively rapid degradation. Similar rates of degradation were found with sodium silicilate and

Coumarin 540 in heptane, and LD-489 in glycerol, systems which only produced moderate energies.

Uranium doped glass, Hg doped lamps, and $CuSO_4$ were also investigated. The U-glass proved to be inefficient. The Hg lamps showed no significant difference in performance from normal lamps. The $CuSO_4$, which was designed to keep infrared light in the lamps from depopulating the excited level of the rod[5], functioned successfully. However, there was a photolytic reaction which caused the $CuSO_4$ to dissociate and deposit copper onto the rod.

Recently, progress has been made on dye-loaded plastics for fluorescent conversion. So far, a large sample rod has withstood a few hundred joules of arc lamp input for 50 shots and developed only minor mechanical distortion. In addition, no visible optical damage was apparent. If this performance can be increased to thousands of shots, then this approach may have considerable value.

Crystalline powder converters are not expected to perform well because of scattering losses due to total internal reflection. If a solid boule of the rare-earth phosphor can be fabricated, it may be possible to have a tubular sheath cut from it to serve as the converter.

The experimental configuration shown in Fig. (2) involved the use of Stilbene 420 and Coumarin 503, both in circulating solutions of ethanol. This resulted in fairly consistent outputs of 10 – 30 mJ for hundreds of shots.

C. Experimental Results

1. Femtosecond Pulse Amplification

With the above configuration, the head was used to amplify 200 fs mode-locked dye laser pulses at 745 nm. In a four pass configuration, the gain per pass was found to be 1.5 or, equivalently, a gain constant of 0.2 cm^{-1}. This gain is certainly adequate for regenerative amplification of a seed pulse. However,

much higher gain, on the order of 180 per pass or 50 cm^{-1}, is possible with laser pumping[6]. This would greatly simplify the amplifier optical design.

2. Pulsed Mode–Locked Operation

Active mode–locking was achieved in the laser cavity with an acousto–optic mode–locker operating at 100 MHz. The modulation depth was varied from 0 to > 50% by adjusting the R.F. input power.

The laser spectrum without intra–cavity elements is illustrated in Fig. (3). The insertion of the mode–locker in the cavity caused frequency modulation of the gain profile as shown in Fig. (4). This feature, of course, limits the effective bandwidth for short pulse generation. The shortest pulse generated in this cavity was approximately 400 ps [see Fig. (5)].

With the addition of a 250 μm thick quartz birefringent filter tuned for transmission at the gain peak, the corresponding bandwidth was controlled to cover a range of ~ 10 nm [see Fig. (6)]. This configuration resulted in a pulse width of 112 psec [Fig. (7)]. This finding compares favorably with that achieved with passive mode–locking at MIT Lincoln Laboratory giving a detector limited figure of ~ 100 psec[7].

The origin of the mode structure in the cavity was studied. Birefringence and etalon effects in the cavity (without the birefringent filter) appear to be negligible. This leads to the suggestion that the addition of the Brewster angled element (the mode–locker) is introducing both cavity losses and astigmatism[8].

D. Scaling to 2" Diameter Rods

The results of this work indicate amplifier scaling to a 2" diameter according to the following:

If we assume a small signal single pass gain given by

$$G = e^{g_o \ell}, \quad g_o = \mu\sigma \tag{1}$$

and consider scaling from a 1/4" diameter rod to a 2" diameter rod with the same doping level of Ti^{+} ions, we have a volume factor of 64x (given by ratio of the radii).

Therefore, to maintain the same gain, the inversion n must be the same as in the 1/4" rod, and thus, the pump power must increase by a factor of 64. Therefore, simply the

$$\text{Pump power (2")} = 64\text{x pump power (1/4")}, \tag{2}$$

for the same doping. This gives an

$$\text{Energy Stored} = 64\text{x } E_{st} \text{ (1/4")}, \tag{3}$$

or equivalently, [64/(0.45 J)] = 28.8 J, based on highest value E_{st} for 1/4" rod. However, this doping level would be too high for infrared absorption of the pump light in a 2" diameter rod. Depending on the pump cavity geometry, the permitted doping level will be much lower. In order to evaluate this point, consider

$$\text{Absorption} = e^{-\alpha \ell}. \tag{4}$$

Currently ~ 90% is absorbed in 1.8 cm, the equivalent of three rod diameters, so that

$$\alpha = 0.058 \text{ cm}^{-1}. \tag{5}$$

If we want 90% absorption in a single pass of 2" rod (5 cm), we must get

$$\alpha_{2"} = 0.02 \text{ cm}^{-1}. \tag{6}$$

Therefore, the doping is reduced approximately three-fold for the same gain, assuming operation is not very close to saturation. Therefore, we have

$$\text{Pump Energy (2")} = 3\text{x pump } (\alpha = 0.058) \simeq 190 \times \text{(1/4" rod)} \simeq 10 \text{ J}. \tag{7}$$

E. Conclusions

Subpicosecond (~200 fs) amplification in a flash-lamp excited $Ti:Al_2O_3$ amplifier has been achieved for the first time. The demonstrated gain is sufficient for operation as a regenerative system. Active mode-locking of $Ti:Al_2O_3$ has also been performed with the resulting generation of a pulse width of ~ 112 ps, a

value apparently limited by the intrinsic dispersion and astigmatism of the configuration used. Both of these factors admit compensation by appropriate measures so that considerably shorter pulses could be produced by this means. Overall, these results indicate that $Ti:Al_2O_3$ is an excellent material for short pulse amplification in the near infrared.

III. REFERENCES

1. P. Brockman, C. H. Bair, J. C. Barnes, R. V. Hess, and E. V. Browell, Opt. Lett. 11, 712 (1986).

2. K. Boyer, private communication; C. K. Rhodes, "Construction of $Ti:Al_2O_3$ Laser Amplifier", Final Report, P.O. CX-7455, Lincoln Laboratory, January, 1987.

3. P. Lacovara, L. Esterowitz, R. Allen, "Flash-lamp-pumped $Ti:Al_2O_3$ Laser Using Fluorescent Conversion," Opt. Lett. 10, 273 (1985).

4. P. Lacovara, L. Esterowitz, "Flashlamp-pumped Titanium Doped Sapphire Laser," Zig Zag Conference Proceedings, ThA12-1 (1986).

5. E. G. Erickson, "Preliminary Observations on a Flashlamp Pumped, Wide Spectral Width $Ti:Al_2O_3$," CLEO, ThF-1 (1986).

6. K. F. Wall, private communication (see attached preprint).

7. P. Schulz, private communication.

8. A. E. Siegmann, Lasers, University Science Books (1986).

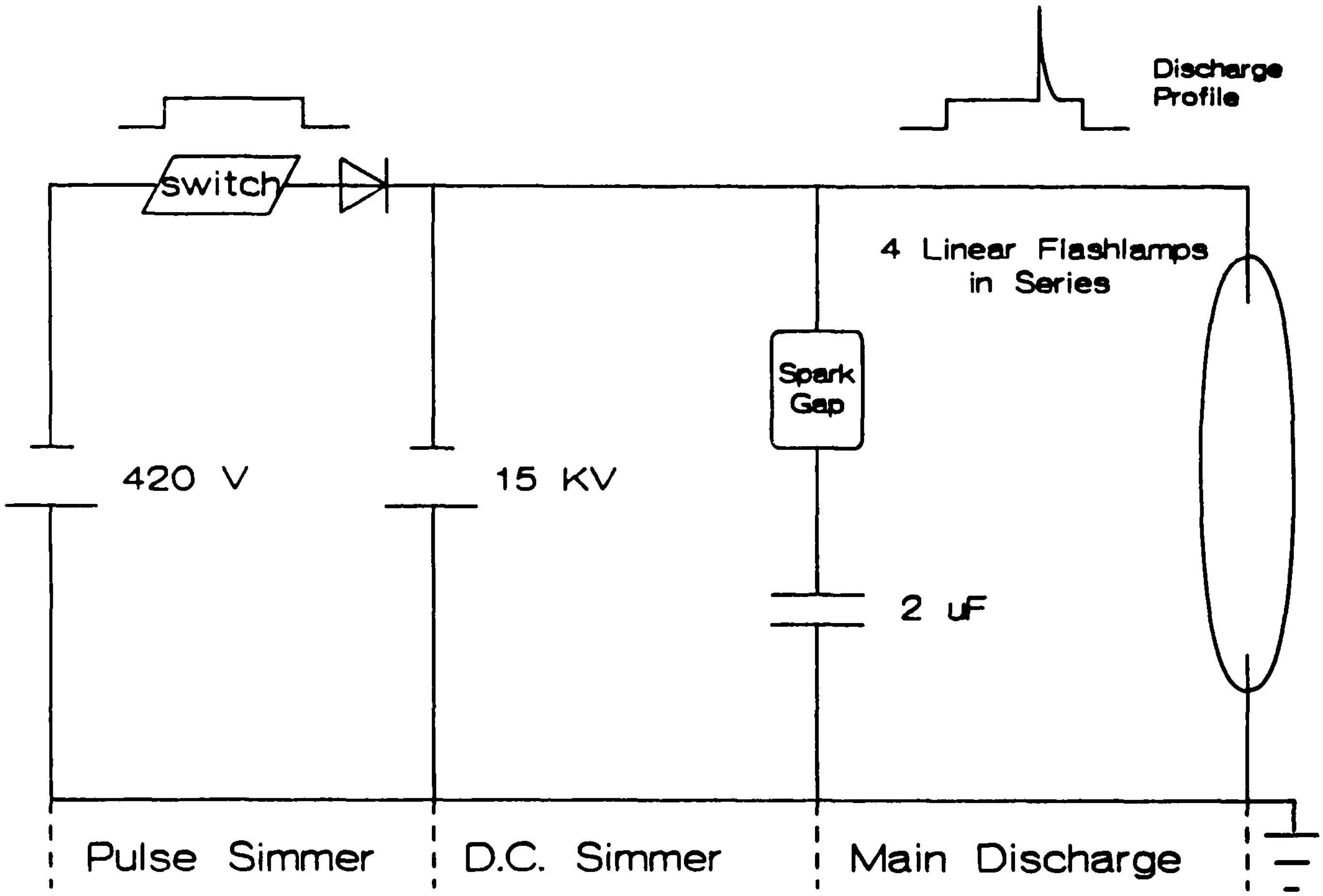

Fig. (1): Power supply design.

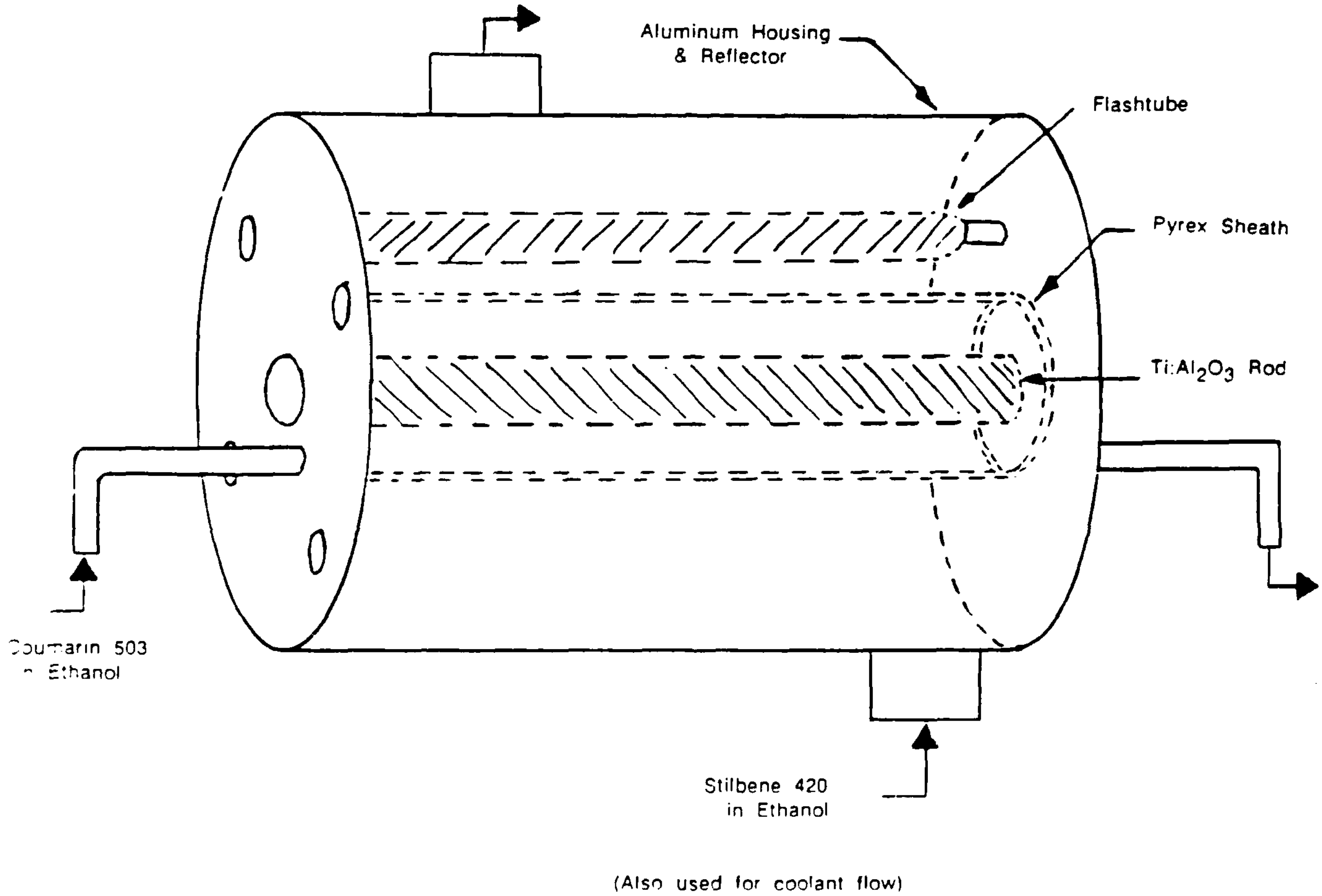

Fig. (2): Head design.

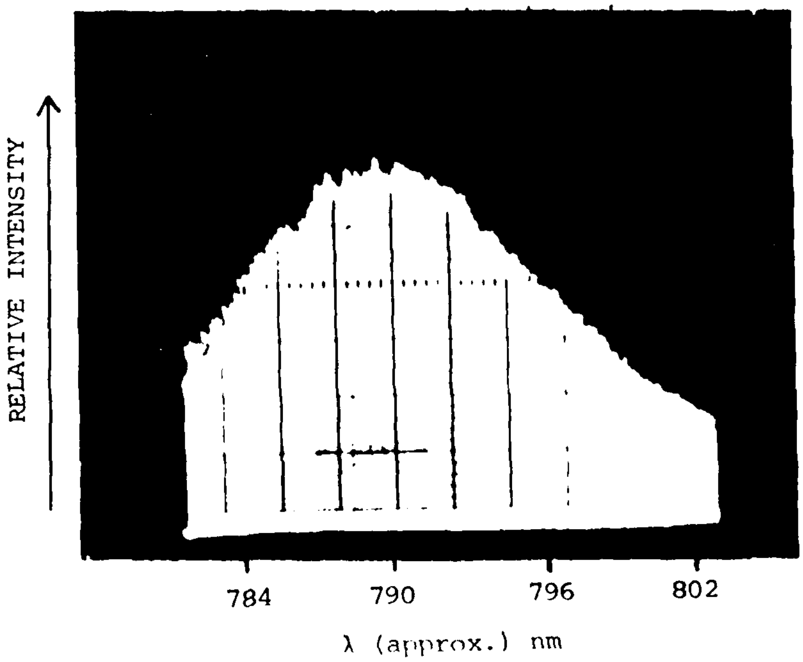

Fig. (3): Spectrum of laser without intra-cavity elements.

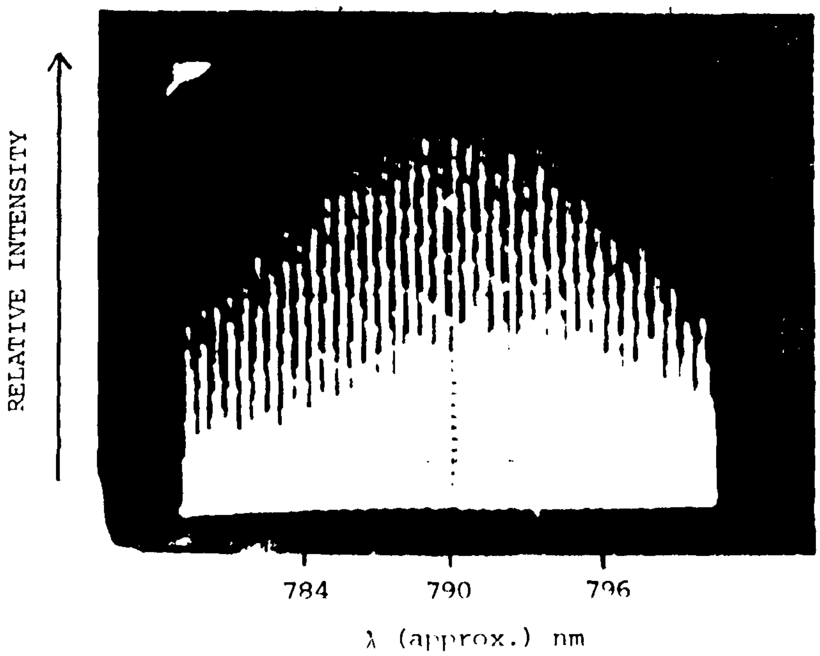

Fig. (4): Spectrum with mode-locker in cavity.

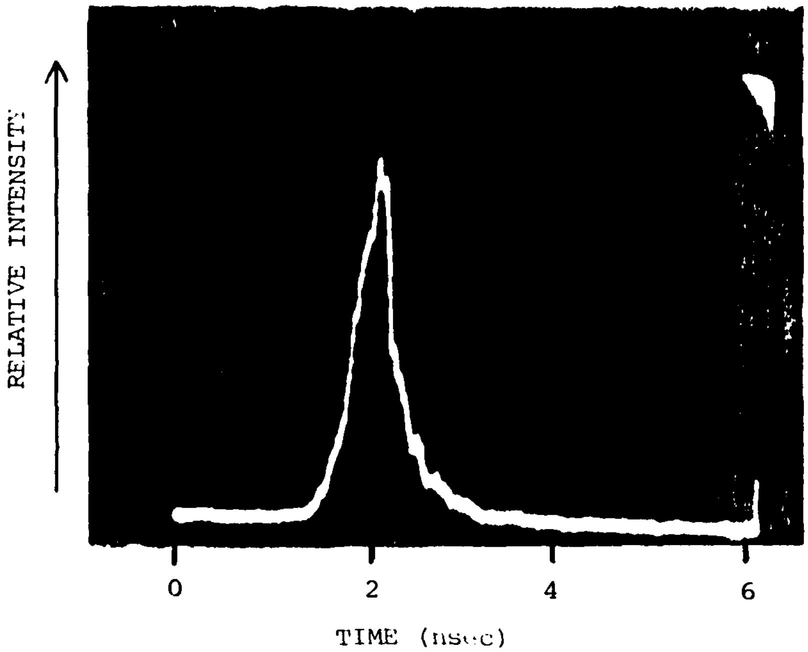

Fig. (5): Trace of mode-locking without filter. FWHM = 400 psec.

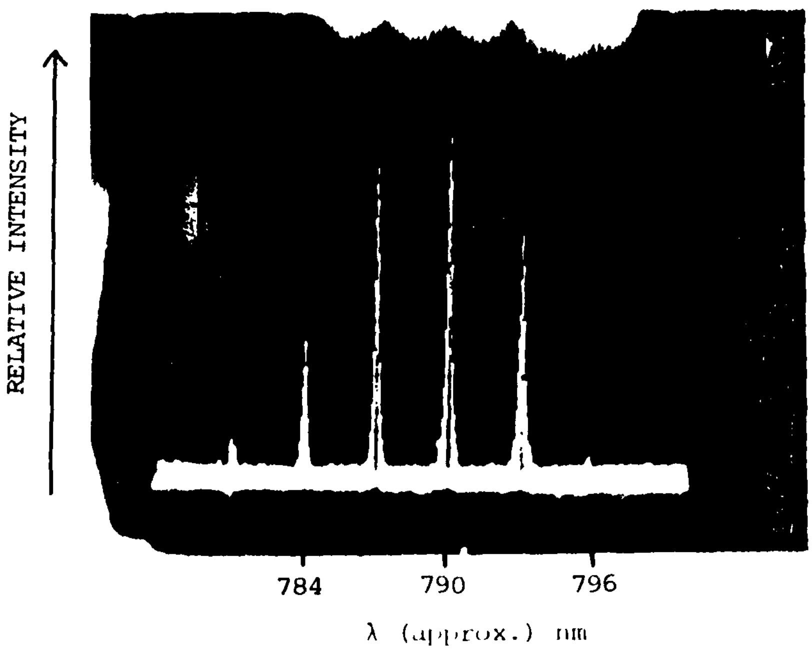

Fig. (6): Spectrum with mode-locker and birefringent filter.

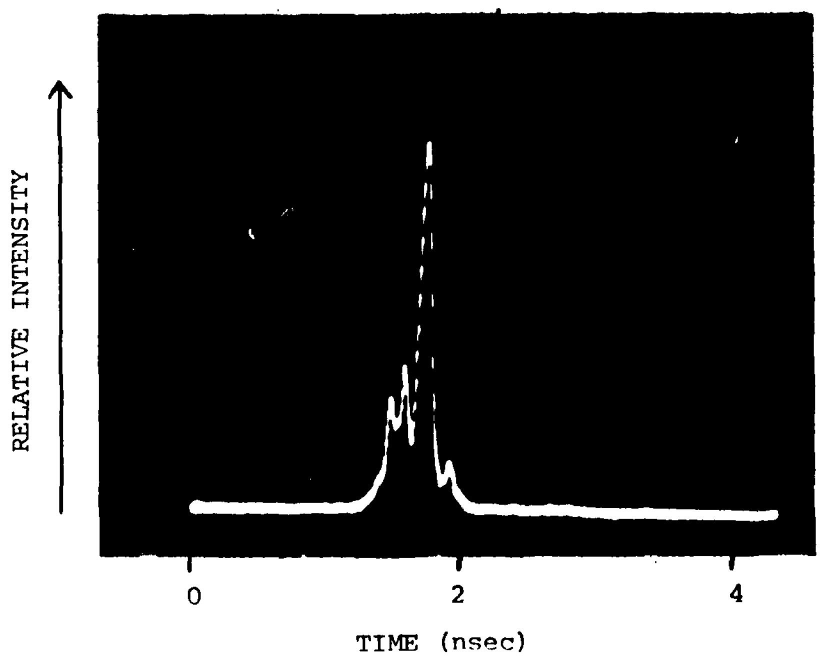

Fig. (7): Trace of mode-locked pulse with filter. FWHM of main pulse = 112 psec.